Inferring Atmospheric Turbulence Structure Using Synthetic Aperture Radar Images of the Ocean Surface

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LONG-TERM GOAL

My long-term goal is to learn how to remotely sense the properties of the marine atmospheric boundary layer, including mean wind speed and direction, the depth of the boundary layer, and the spatial distribution of atmospheric turbulence, using at least synthetic aperture radar (SAR).

SCIENTIFIC OBJECTIVES

My first objective for this year was to continue the analysis of two data sets (ONR-MBL/ARI and Shoaling Waves) made up of simultaneous in situ turbulence measurements and SAR imagery, to see what atmospheric information I could extract from the SAR image and verify with the in situ data. My second objective was to complete a paper comparing low grazing angle radar backscatter and low wind measurements taken with the UMASS FOPAIR system. My third objective was to complete a review article whose title is: "Footprints of Atmospheric Turbulence in Synthetic Aperture Radar Images of the Ocean Surface: a Review."

APPROACH

My approach for the first objective is based on SAR image analysis (for extracting hypothetical atmospheric-turbulence signatures) and time-series analyses. The analysis of time series includes "quadrant analysis" using various definitions of the mean flow, spectral analysis, and various moving operations. For my second objective I worked with Dr. Delwyn Moller of JPL to analyze existing data that allows the comparison of low grazing angle radar backscatter images of the ocean surface off of Duck, NC with simultaneous wind speed and direction data under light wind speed conditions.

WORK COMPLETED

With my colleagues I have submitted four papers. The first is a paper with Dr. Bernard Walter of NWRA as first author on the analysis of the ONR-MBL/ARI data set (Walter et al., 1998). The second paper is on the analysis of the Shoaling Waves data set (Mourad et al., 1998). The third is a review paper on extracting information on atmospheric turbulence from SAR imagery (Mourad, 1998a). The fourth is a paper comparing low grazing angle backscatter measurements with measurements of wind

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speed and direction under low wind speed conditions (Moller et al., 1998). I've also made three presentations (Mourad, 1997; Mourad, 1998b,c).

RESULTS

(1) A comparison of co-located SAR and in situ turbulence measurements shows that the SAR images large eddies which act as a modulating influence on surface-layer turbulence, whose structure may be described as being of smaller spatial scale, and fundamentally three-dimensional. Indeed, it is only in spectral analysis that the large eddy scales inferred from the SAR image show up in the in situ data. Also, the orientation of SAR streaks associated with atmospheric roll vortices in the images at my disposal is along the vertically integrated mean wind direction, not the surface wave direction, as expected by theory but not appreciated by those working in the field of SAR image analysis. Preliminary comparison with algorithms for remotely sensing wind from SAR images shows that those algorithms (at least for a HH-pole RADARSAT image) over-predict the wind by about 30%. Finally, it is difficult to get a tight estimate of boundary layer depth from SAR streak spacing alone. (2) We have identified critical wind speeds associated with wind-driven gravity capillary waves of sufficient strength to cause significant radar backscatter at low grazing angles. These speeds differ under rising versus falling wind conditions.

IMPACT/APPLICATION

SAR images that contain streaks can be used to infer boundary layer properties such as mean wind speed and direction, with further refinement of existing algorithms. There is promise that surface layer turbulence statistics may also be extracted from SAR images. Also, it may be prudent to have simultaneous rapid-scan GOES cloud images and SAR images if one wants to infer boundary-layer height remotely because of the possibility of subsidence, and the relatively weak relationship between SAR streak spacing and boundary layer depth. Moreover, we have evidence of hysteresis in radar backscatter versus wind speed: this means that there is a difference between the wind speed necessary to generate gravity-capillary waves of sufficient strength to cause measurable radar backscatter, compared with the wind speed necessary to maintain gravity-capillary waves. This work is the first field study of this question and is important for interpreting scatterometer images, where there is a lack of understanding of the relationship between radar backscatter and wind at low wind speeds.

TRANSITIONS

Algorithms for extracting information on the atmospheric boundary layer from SAR images sometimes need information from other remote sensors to give robust and well-constrained estimates of that information.

RELATED PROJECTS

A closely related project includes my recently funded study by the National Science Foundation to look at the signature of atmospheric turbulence over Lake Michigan in simultaneous SAR imagery and in situ turbulence measurements.

REFERENCES/PUBLICATIONS

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PATENTS

NA

IN-HOUSE/OUT-OF-HOUSE RATIOS

100% out of house, at the University of Washington.